Section Life Cycle Management

LCA Discussions

The Econo-Environmental Return (*EER*)

A Link between Environmental Impacts and Economic Aspects in a Life Cycle Thinking Perspective

Gontran F. Bage* and Réjean Samson

CIRAIG – Interuniversity Reference Center for Life Cycle Assessment, Interpretation and Management of Products, Processes and Services, École Polytechnique de Montréal, Department of Chemical Engineering, P.O. Box 6079, Station Centre-Ville, Montréal (Québec), H3C 3A7, Canada

* Corresponding author (gontran.bage@polymtl.ca)

DOI: http://dx.doi.org/10.1065/lca2003.06.119

Abstract

Aim and Background. Many analytical tools have been developed to support the implementation of sustainable development. Principal among these are the ones that are based on physical aspects such as life cycle assessment (LCA), while others focus on non-physical aspects, namely on monetary concepts, such as life cycle costing and total cost assessment. Each kind of tool is designed to assess a specific aspect (environmental or economic) of the entire life of a good or a service. Unfortunately, even if the literature clearly states the advantage of combining these tools, case studies with global conclusions considering both aspects are still rare. Most often, studies conclude separately on each aspect; environmental impact and cost assessment.

Definitions. The already published concept of *Return on Environment* (*ROE*), inspired from return on investment, is a first step in the right direction for combining these tools and hence, achieving better alternative comparisons. Considering some limitations as to the ease with which it compares two or more similar goods, two new indexes are suggested here. The first one, called the *Environmental Return* (*ER*), focuses only on environmental aspects. It allows the comparison on an environmental basis of several goods or services fulfilling the same function. The second definition, called the *Econo-Environmental Return* (*EER*), is an index created by the combination of the environmental impact assessment results (such as an LCIA) and those from an economic assessment (such as an LCC or a TCA). From a simple decision rule, a decision-maker can compare several goods on both environmental and economic aspects.

Discussion and Conclusion. A simplified case study is used to present a numerical application of these two definitions and to interpret their different results and conclusions. Two different types of broadloom carpet, PET (recycled polyester) and nylon, are compared. When they are only compared on an LCIA basis, the PET carpet is preferred over the nylon one, while the opposite is true when they are compared on both economic aspect and environmental impact bases. The major advantage of the *Econo-Environmental Return* is that two goods can be compared without requiring a specific industrial sector reference value.

Keywords: Decision-making; econo-environmental return (EER); environmental impacts; environmental return (ER); life cycle assessment (LCA); life cycle costing (LCC); return on environment (ROE); total cost assessment (TCA)

1 Aim and Background

While life cycle assessment (LCA) has gained importance in the way decision-makers are managing projects over the last ten years, its economical counterpart, life cycle costing (LCC) is well established, mainly in building construction since the 1970s [an LCC historical development can be found in Kirk and Dell'Isola (1995) and Woodward (1997)]. For a comparison between life cycle costing (LCC) and total cost accounting (TCA), which can be seen as a subset of LCC, see Wrisberg et al. (2002). Based on an environmental impact comparison between two processes producing corrugated containerboard packaging, Frischknecht (1998) and later, Ross (2002) concluded that the real decision regarding the alternative to be selected must be based on an LCA, but also on a financial and social cost assessment. Physical metric and non-physical metric analytical tools have been used together in the last years to consider both economic aspects and environmental impacts in choosing between alternatives. Depending on the scope of costs (private costs only or both private and societal costs; for the latter, the costs of the environmental impacts have to be assessed) and the application of the cost study (i.e. accounting, budgeting, design), this support may lead to the combining of several tools such as environmental cost accounting, full cost environmental accounting, total cost assessment, life cycle cost assessment and life cycle accounting (for a definition of these terms, see US EPA (1995)). Even if there is some confusion concerning the exact term to be used when economic parameters are included in an environmental assessment, there is no doubt as to the necessity of this inclusion.

A few tools have been developed to combine environmental impacts and economic aspects. The *Economic Input-Output LCA model* (*EIO-LCA*) developed at Carnegie Mellon University provides the conventional pollutants and the cost of the supporting activities involved in the production of a given quantity of a product (Matthews and Small 2000). The *EIO-LCA* model does not produce a detailed LCA nevertheless, it can be useful to generate both impact and economic data on an industry-average range. Another tool incorporating economical data into a classical LCA, the *Relative Mass-Energy-Economic method* (*RMEE*) has been developed to identify where to draw a system boundary (Raynolds et al. 2000). A unit process is included inside the

system boundary if its mass ratio (the ratio between the mass value of a unit process input and the functional unit mass value), its energy ratio or its economic ratio is higher than a predefined cut-off ratio. Starting from the closest unit process of the functional unit, the system boundary is drawn by including all unit processes that respect this selection criterion. The *RMEE* method has two main advantages: 1) it is not necessary to complete an LCA in order to identify which unit can be excluded and 2) it considers an expensive input, having low mass and energy (precious metals for example), that is produced by an upstream process requiring high mass and high energy. For building products, the *BEES* tool (*Building for Environmental and Economic Sustainability*) is used to assess the environmental impacts that occur during the raw material acquisition, manufacture, transportation, installation, use and disposal stages and the total costs associated with the initial investment, replacement, operation, maintenance, repair and disposal of a specific building product (Lippiatt 2000, Lippiatt and Boyles 2001). *BEES* is mainly used to compare at least two building products having the same functional unit. The tool's outputs are the environmental impacts of the compared products, their total costs and a global index that includes the environmental impacts and total costs. This global index is based on the importance the user attributes to the costs compared to the environmental impacts. Recently, the concept of *Return on Environment* (*ROE*) has been introduced in the LCA literature (Hunkeler and Biswas 2000, Hunkeler 2001). This *ROE* is an index based on the life cycle cost, the selling price and a scaled impact assessment for a given product. According to the authors, the return value (that they compared to the economic concept of return on investment) can give information about the quality of the data collected for the LCA. Furthermore, it allows the comparison of the *ROE* of a given product to the standard *ROE* value of its industrial sector when many products' *ROEs* are calculated. A more detailed discussion about the *ROE* definition is presented in the next section.

If it is recognized that both environmental impacts and economic aspects have to be considered for sustainable development and better decision-making, and if combined tools are being developed, do studies using these combined tools differ from classical LCA studies? The answer to this question might possibly be yes when one considers how the studies are conducted but no when the interpretation of these studies are taken into account, depending on whether the importance is on environmental impacts or economic aspects. Some LCC approaches can be found in LCA studies [such as in Keoleian et al. (2000); Sonesson et al. (2000)]. In the first study, two different types of houses (standard and energy-efficient) with the same functional unit are compared on the basis of their material and the energy used during the life cycle as well as their total costs. In the second study, different biodegradable waste treatment scenarios are compared. Here again, the scenarios are compared on the basis of their environmental impacts (energy turnover, global warming potential, acidification emissions, eutrophicating emissions and photochemical oxidant formation) and their total costs and benefits (benefits result from the use of biogas for vehicle fuel, organic fertilizer and heat; all three produced by the biodegradable waste treatment). However, in both studies, the most preferable alternatives can be opposite whether the conclusion is based on the environmental impacts or on the economic considerations. There is no general conclusion considering both environmental and economic impacts.

The aim of this paper is to propose an index for comparing several alternatives on both environmental impacts and economic aspects at the same time. This index is developed in the second section, while it is applied in the third. The fourth section discusses the index's applicability.

2 Definitions: The Environmental Return

2.1 Review of the Return on Environment (ROE) definition

There is actually a tool, more precisely a comparison index, that combines both environmental impacts and economic aspects associated with the entire life of a product. This index, called the *Return on Environment (ROE)*, has been proposed by Hunkeler and Biswas (2000). The *ROE* is a ratio of the economic aspects over the environmental impacts [see equation (1) defined by Hunkeler and Biswas (2000)]. The economic aspects, called the 'reduced life cycle cost' are represented by a ratio between the life cycle cost and the selling price, while the environmental impacts are scaled between 1 and 100. Both numerator and denominator are dimensionless.

$$ROE = \frac{Life\ Cycle\ Cost / Selling\ price}{Scaled\ Impact\ Assessment} \cdot 100\% \qquad (1)$$

This index can be used for several reasons. It is a decision-making tool as to whether a more accurate environmental assessment is required. Based on case studies, the *ROE*'s typical range is 2–20% (this *ROE* typical value is to be validated with more case studies conducted in different industrial sectors). According to Hunkeler and Biswas (2000), either the LCC or the LCA of a good having an *ROE* out of this range should be reconsidered. However, the *ROE* appears to be a restrictive comparison index since the statistically valid index value of an industrial sector requires the assessment of many goods. This index may also be used to calculate a first estimate of the life cycle cost of a product for which a standard *ROE* value can be fixed and both the selling price and the impact assessment are known (or vice versa if the life cycle cost is known). Finally, as both the environmental impacts and the economic aspects are normalized, this index can be used to compare goods or services having different characteristics.

An observation can be made in the interpretation of this return concerning the robustness of an index based on a selling price. The selling price has been introduced in equation (1) to normalize each good to be compared without using a product specific factor (such as the mass or density). In theory, the selling price increases with the life cycle cost. So, two different goods (such as a house and a coffee-maker) can be compared even if their economic values are in different ranges. However, if two similar goods are compared (such

as two different coffee-makers), for which the life cycle costs should be equivalent and so for which normalization would not be required, using the reduced life cycle cost may affect the *ROE* for the introduction of the company's competition into the market by considering the selling price. If one of the producers is more competitive and decides to sell his coffee-maker at a lower price, the reduced life cycle cost will increase, which in turn, increases the *ROE*'s value.

The *ROE* can be viewed as a useful estimation tool rather than a comparison tool, for the use of the selling price may affect the comparison of two goods fulfilling the same functional unit. Hence there is still a need for an index comparing similar goods or services. In the following sections, two new indexes (the *Environmental Return* and the *Econo-Environmental Return*) are proposed.

2.2 A new definition: the Environmental Return (ER)

In economics, the return on investment is defined as the interest rate that equalizes the annual discounted benefits and the annual discounted costs of a project. This rate, *i*, can be calculated from equation (2) (Kirk and Dell'Isola 1995) where *PWA* (present worth annuity) is the ratio between the annual costs and the annual benefits and n is the duration of the project.

$$PWA = \frac{(1+i)^n - 1}{i \cdot (1+i)^n} \qquad (2)$$

Translating this definition into a life cycle thinking context, the *Environmental Return* (*ER*) could be the index (rate) that ties the environmental benefits (positive impacts) and the environmental impacts (negative impacts) incurred during the entire life cycle of a good or a service. To avoid any confusion, it is more appropriate in a life cycle context to use the term 'index' and to keep the term 'rate' associated with the investment concept. Acknowledging that time considerations are generally excluded from the assessment of environmental impacts (ISO 2000) and that if environmental impacts require to be discounted over time, the choice of the appropriate discount rate depends on the study and its objectives (Hellweg et al. 2003), then all environmental impacts can be referenced to a similar point in time and so the parameter *n* in equation (2) can be set to one (1) year. Equation (2) for the return on investment can then be translated into equation (3) and, in turn, to equation (4) in order to obtain the *Environmental Return* (*ER*). With environmental impacts referenced to a similar point in time, it becomes possible to either use non discounted values (as it is most often the case) or to use discounted impact values. In these equations, $EnvI^+$ refers to the positive environmental impacts (the environmental credits or benefits resulting from a recycling loop), while $EnvI^-$ refers to the negative environmental impacts (usually called the environmental impacts). Even if most of the time the positive environmental impacts are included in the negative ones, it is possible to retrieve these values from a contribution analysis on all the different processes considered in the studied system.

$$Environmental\ ratio = \frac{EnvI^-}{EnvI^+} = \frac{(1+ER)-1}{ER \times (1+ER)} \qquad (3)$$

$$ER = \frac{EnvI^+ - EnvI^-}{EnvI^-} \qquad (4)$$

Three remarks must be made regarding this definition of the *Environmental Return*.

1. Both the positive and the negative environmental impacts could be associated either with a single impact category (the global warming potential for example) or with a group of aggregated impacts. According to his study's objectives, the user has to decide if a single or an aggregated impact is more appropriate. However, both positive and negative environmental impacts have to be expressed in the same form; either a single or an aggregated impact.
2. The value of the environmental return for a single good has no meaning by itself. On the other hand, its sign can be interpreted: a positive *ER* means that the positive environmental impacts are higher than the negative ones; a negative *ER* indicates the opposite.
3. The value of the environmental return has a meaning only when several goods (all having the same functional unit) are compared. The good having the highest *ER* must be considered as the most environmentally friendly.

The *ER* focuses only on the environmental impacts, and to be consistent with what has been stated above (that both environmental impacts and economic aspects must be used for comparing several goods), a second comparison index needs to be introduced before giving an example of the application of the *Environmental Return*.

2.3 The econo-environmental return (EER)

The introduction in the LCA literature of a combined environmental and economic index for comparing several goods has been initiated from the observation that most of the case studies using combined tools conclude separately on environmental and economic aspects. The aim of this paper is to provide decision-makers with an index that allows for comparing, for both aspects at the time, two or more goods having the same functional unit.

As previously developed for the *ER* and based on the concept of return on investment, there is a need for a dimensionless ratio that includes both environmental impacts and economic aspects. In light of the fact that environmental impacts can be positive or negative, one observes that the value of the economic aspects[1] follows in kind. Suppose that a good has a resale value at its end of life compared to another good having no residual value, a positive value (a benefit) has to be included in the first good economic impact assessment [for information about how to establish a LCC and which costs have to be included in it, see Woodward (1997), ASTM (2000); and for the importance of including the

[1] In this section, the term 'economic aspects' is used to talk about the total costs incurred during the entire life cycle of the good either from a life cycle costing or a total cost accounting point of view. The applicability of both approaches is developed in the Discussion section.

embedded environmental costs into a LCC, see Kitzman (2001)]. Assuming that the costs and benefits are separated, such as positive and negative environmental impacts are, the *econo-environmental ratio* (inspired from the *PWA*) is given by equation (5) in which *EconI*⁻ and *EconI*⁺ are the negative economic aspects (costs) and the positive economic aspects (benefits) respectively. As for the *ER* (see equation (3), the *econo-environmental ratio* is associated with the right-hand part of equation (2) where the rate *i* is translated into the *Econo-Environmental Return (EER)* and the parameter *n* is fixed at one (as it was for the *ER*). Once again, this leads to an index for which all data are referenced to a similar point in time. Data that are introduced in the index have to be already discounted (at least for the economic values). Equation (6) presents this association, while equation (7) gives the value of the *EER*. Once again, the time parameter *n* of equation (2) has been set to one because all the economic values in the assessment of the total costs and the total benefits are discounted for a given reference time. Therefore, neither the environmental impacts nor the economic values included in the definition of the *EER* are time dependant.

$$econo-environmental\ ratio = \frac{EnvI^-}{EnvI^+} \cdot \frac{EconI^-}{EconI^+} \qquad (5)$$

$$\frac{EnvI^-}{EnvI^+} \cdot \frac{EconI^-}{EconI^+} = \frac{(1+EER)-1}{EER \times (1+EER)} \qquad (6)$$

$$EER = \frac{EnvI^+ \cdot EconI^+ - EnvI^- \cdot EconI^-}{EnvI^- \cdot EconI^-} \qquad (7)$$

As for the *ER*'s definition, some observations must be made for this *EER* definition.

1. Similarly to *ER*, both the positive and the negative environmental impacts could be associated with either a single impact category or with a group of aggregated impacts. However, both environmental impacts have to be expressed in the same form; either a single or an aggregated impact.
2. $EconI^-$ and $EconI^+$ have to be discounted using the same discount rate and the same reference time.
3. The sign or the value of a single *EER* cannot be directly interpreted in reference to the economic and environmental meaning of a good. Because the *econo-environmental ratio* is a function of two ratios (economic and environmental), a small ratio for one aspect may compensate for a high ratio for the other, leading to a positive *EER*. So, one cannot tell the economic and environmental significance of a good by simply observing the sign of the *EER*.
4. As a continuation of the previous point, the *EER* value has significance only when two goods or more (all having the same functional unit) are compared. The good having the highest *EER* value must be considered as the best compromise between the economic and the environmental aspects among all the compared goods.
5. As the *EER* attaches the same magnitude (importance) to environmental impacts and economic aspects, the decision-maker's priorities must reflect the same importance.

2.4 Relative return

For use in a more general context, the two indices previously defined in this section are modified here. In the *ER* and the *EER* definitions [equations (4) and (7) respectively], negative and positive parameters are distinct. However, it may not be unusual to have either the total environmental impacts or the total costs without the opportunity of differentiating the positive from the negative values. Most of the time, in such cases, the known parameters are negative (negative economic and environmental impacts) from which the positive values are already subtracted. Some adjustments are necessary in such cases in order for the definitions to be applicable.

In this context, it is necessary to identify a good of reference (the choice of the good among those to be compared does not have any influence on the final results). The unknown parameter values for this good are set equal to the known parameter values. Values for the unknown parameters for all the other goods are then fixed to the values of the reference good. For example, if $EconI^+$ is unknown but $EconI^-$ is known, the reference good $EconI^+$ value is set to the $EconI^-$ value of that good. The $EconI^+$ value of all the other goods is then fixed to the reference good $EconI^+$ value (which is now $EconI^-$). From this adjustment, the good of reference *ER* (or *EER*) is null (0%). So a good is preferred to the good of reference, if its *ER* (or *EER*) is higher than 0%. The development of the equations for the relative return (both *ER* and *EER*) is provided in appendix.

3 Results

Now that the return that takes into account only the environmental impacts has been redefined and that a new concept incorporating both economic aspects and environmental impacts has been developed, these indices can be used to compare two goods. Instead of developing a full LCA and economic assessment for two goods in order to get the necessary data required by the *ER* and the *EER*, an already published case study (Lippiatt and Boyles 2001) has been considered.

The compared goods are two different types of broadloom carpet: one made from nylon and installed with conventional glue and the other made from recycled polyester (PET) and installed with low-VOC glue. The data provided here (environmental impacts and total costs) are given on the basis of the functional unit, set to 0.09 m^2 of installed carpet for 50 years (Lippiatt 2000). **Table 1** presents the data used for

Table1: Environmental impact and economic aspect data

		Nylon carpet[a]	PET carpet
Environmental impacts (Points[b])	$EnvI^-$	96	49
	$EnvI^+$	96	96
Economic aspects ($)	$EconI^-$	4,57	10.21
	$EconI^+$	4,57	4.57

[a] Nylon carpet is considered as the reference good
[b] Weighted summation of the six impact category scores, each category has the same weight (see Lippiatt 2000)

this case study. The environmental impact category is a weighted summation of six environmental impact categories (acidification, eutrophication and global warming potential, indoor air quality, natural resource depletion and solid waste generated). For environmental impacts and total costs[2], the lower the value, the better the good. The generated data are total costs and environmental impacts (*EconI⁻* and *EnvI⁻* respectively), meaning that the relative return approach is required to compare both carpet types. For the case study, the nylon carpet has been selected as the reference good. This explains the similar values obtained for the nylon carpet's positive and negative impacts, and the similar values for both carpet's positive impacts. The preference between the nylon and PET carpets would have been the same if the PET carpet had been selected as the reference good.

From a simple observation of the data in Table 1, it appears that the PET carpet must be preferred to the nylon carpet when compared on an environmental basis (49 negative environmental points compared to 96), although the nylon carpet is cheaper than the PET carpet. In such a context, an index combining both environmental and economic aspects is necessary to select the most appropriate good. **Table 2** presents the relative *ER* and relative *EER*, their respective ratio and the preferred good. For each approach, the relative return and its ratio lead to the same conclusion. On a strictly environmental impact basis, the results agree with the previous observations; the PET carpet is preferred to the nylon carpet due to the higher environmental impacts of the latter. When both environmental impacts and total costs are considered, results show the preference is now for the nylon carpet. This means that the difference in total costs in favour of the nylon carpet compensates for its highest environmental impacts. Even if, in this example, the nylon carpet is environmentally and economically preferred to the PET carpet, the reader should observe that this preference is less important than the strictly environmental preference of the PET carpet over the nylon carpet. In the latter case, the absolute difference from the equivalence between both carpets is about 96% while it is only 12% when both environmental and economical aspects are considered. A larger difference in total costs in favour of the nylon carpet would increase this absolute difference from the equivalence.

Table 2: Relative returns

$ER_{PET/Nylon}$	95,9%	PET carpet is environmentally preferred
Ψ	1,96	
$EER_{PET/Nylon}$	−12,3%	Nylon carpet is environmentally and economically preferred
ξ	0,88	

[2] BEES related documents (Lippiatt 2000, Lippiatt and Boyles 2001) use the term 'life cycle costing' to define the assessment of total costs, while the term 'total cost accounting' is used according to the distinction made between both terms in Wrisberg et al. 2002 because no costs are linked to environmental impacts in BEES' total cost assessment.

4 Discussion

As previously shown in the example, the preference for a good may change when economical aspects are considered together with the environment impacts. This is a good example of how considering only one aspect (the environmental impacts in this case) may lead to a non-optimal decision. In a life cycle management point of view, one cannot focus his decision-making on only one aspect of the entire life cycle. The decision-maker must have a global perspective of the problem, understand the type of dilemma he is facing (reducing the environmental impacts leads to an internal cost increase, while external costs play a major role in the total cost if no environmental impact reduction is carried out), and finally use the appropriate tools to make the best decision.

One advantage of the *EER* is that it can be used in studies considering different analytical tools. The environmental impact values (positive and negative) may come from one impact category or a group of impact categories aggregated together. The economic values (also positive and negative) may be based on an LCC or a TCA. It is certain that the conclusion reached may not be the same depending on which tool is used; it is the decision-maker's responsibility to identify which tool should be used with respect to the study's objectives. Because the *EER* has been designed to be flexible, it is able to combine the answers obtained from two tools into a single index, which respects the study's objectives and can be easily interpreted by the decision-maker. This type of decision based on combined perspectives (economic and environmental) carries more weight than one made on only one aspect (Wrisberg et al. 2002); the simplified case study presented here is a good example.

While the *Return on Environment* (*ROE*) developed by Hunkeler and Biswas (2000) requires the assessment of many LCA cost-based case studies to get a statistically valid comparison index in a given sector, both the *Econo-Environmental Return* (*EER*) and the *Environmental Return* (*ER*) present the advantage of being able to compare two goods or services (having the same functional unit) without the necessity of having evaluated in the past other similar products. The *EER* and the *ER* are fast and easy comparison indices to use.

5 Conclusion and Outlook

When applying sustainable development principles, the need for assessment tools combining both environmental impacts and economic aspects from the entire life cycle of a good or a service is obvious. Such tools must synthesize the answers associated with these impacts and aspects in a manner that helps a decision-maker comparing different goods or services having the same functional unit. The *Econo-Environmental Return (EER)* is an index created by the combination of the environmental impact assessment results (such as an LCIA) and those from an economic assessment (such as an LCC or a TCA). From a simple decision rule, a decision-maker can compare several goods on both environmental and economic aspects. Because the *EER* has been developed regardless of the tool used to analyze one aspect of the entire life cycle of a good, it is flexible for any type of data and can be used whatever the study's objectives.

References

ASTM (2000): Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, ASTM Designation: E917-99. American Society for Testing and Materials (ASTM), West Conshohocken, PA, USA

Frischknecht R (1998). Life cycle inventory analysis for decision-making: Scope-dependent inventory system models and context-specific joint product allocation. Zurich, Swiss Federal Institute of Technology: 255

Hellweg S, Hofstetter TB, Hungerbühler K (2003): Discounting and the Environment – Should Current Impacts be Weighted Differently than Impacts Harming Future Generations? Int J LCA 8 (1) 8–18

Hunkeler D (2001): Return on environment, addressing the need for normalization and validation in ecometrics. In: Proceedings of the1st International Conference on Life Cycle Management, LCM2001, August 27–29 2001. Copenhagen, Denmark

Hunkeler D, Biswas G (2000): Return on environment – An objective indicator to validate life cycle assessments? Int J LCA 5 (6) 358–362

ISO (2000): Environmental management – Life cycle assessment – Life cycle impact assessment, ISO 14042. International Standard Organization (ISO), Geneva, Switzerland

Keoleian GA, Blanchard S, Reppe P (2000): Life-cycle energy, costs, and strategies for improving a single-family house. Journal of Industrial Ecology 4 (2) 135–156

Kirk SJ, Dell'Isola AJ (1995). Life cycle costing for design professionals. McGraw-Hill, New York

Kitzman KA (2001): Environmental cost accounting for improved environmental decision making – To manage and reduce environmental costs, it is first necessary to understand them. Pollution engineering 33 (11) 20–23

Lippiatt BC (2000). Building for environmental and economic sustainability technical manual and user guide. BEES 2.0. Gaithersburg, MD, National Institute of Standards and Technology, Office of Applied Economics, Building and Fire Research Laboratory: 140

Lippiatt BC, Boyles AS (2001): Using BEES to select cost-effective green products. Int J LCA 6 (2) 76–80

Matthews HS, Small MJ (2000): Extending the boundaries of life-cycle assessment through environmental economic input-output models. Journal of Industrial Ecology 4 (3) 7–10

Raynolds M, Fraser R, Checkel D (2000): The relative mass-energy-economic (RMEE) method for system boundary selection, Part 1: A means to systematically and quantitatively select LCA boundaries. Int J LCA 5 (1) 37–46

Ross S, Evans D (2002): Use of life-cycle assessment in environmental management. Environmental Management 29 (1) 132–142

Sonesson U, Björklund A, Carlsson M, Dalemo M (2000): Environmental and economic analysis of management systems for biodegradable waste. Resources, Conservation and Recycling 28 (1–2) 29–53

US EPA (1995): An introduction to environmental accounting as a business management tool: key concepts and terms, EPA 742-R-95-001. US Environmental Protection Agency, Office of Pollution Prevention and Toxics, Washington, D.C.

Woodward DG (1997): Life cycle costing – Theory, information acquisition and application. International Journal of Project Management 15 (6) 335–344

Wrisberg N, Udo de Haes HA, Triebswetter U, Eder P, Clift R (Eds) (2002): Analytical tools for environmental design and management in a systems perspective. Eco-efficiency in industry and science. Kluwer Academic Publishers, Dordrecht, The Netherlands

Received: September 23rd, 2002
Accepted: June 16th, 2003
OnlineFirst: June 19th, 2003

Discussion contributions from the LCA community will be well appreciated by the authors.

Appendix: Relative returns and decision rules

Suppose two compared goods, *A* and *B*, have the same functional unit. Assume that neither the positive economic impacts (*EconI+*) nor the environmental benefits (*EnvI+*) are known. Good *A* is set as the reference good. This gives the following relations:

$$EconI_A^+ = EconI_A^-$$

$$EconI_B^+ = EconI_A^+ = EconI_A^-$$

$$EnvI_A^+ = EnvI_A^-$$

$$EnvI_B^+ = EnvI_A^+ = EnvI_A^-$$

Replacing these relations into equation (7), leads to the followings equations for both goods *A* and *B*. The suffix *B/A* means good *B* relative to good *A*.

$$EER_A = \frac{EnvI_A^+ \cdot EconI_A^+ - EnvI_A^- \cdot EconI_A^-}{EnvI_A^- \cdot EconI_A^-}$$

$$EER_B = \frac{EnvI_B^+ \cdot EconI_B^+ - EnvI_B^- \cdot EconI_B^-}{EnvI_B^- \cdot EconI_B^-}$$

$$EER_{B/A} = \frac{EnvI_A^- \cdot EconI_A^- - EnvI_B^- \cdot EconI_B^-}{EnvI_B^- \cdot EconI_B^-} = \frac{EnvI_A^- \cdot EconI_A^-}{EnvI_B^- \cdot EconI_B^-} - 1 = \psi - 1$$

$$EER_{A/A} = \frac{EnvI_A^- \cdot EconI_A^- - EnvI_A^- \cdot EconI_A^-}{EnvI_A^- \cdot EconI_A^-} = 0$$

If $EER_{B/A}$ is positive and non-null, then good *B* is economically and environmentally preferable to good *A*. Acknowledging that Ψ is the product between the environmental impact ratio and the total cost ratio, the following decision rules can be defined:

- $\Psi > 1$ Good *B* is economically and environmentally preferable to good *A*
- $\Psi < 1$ Good *A* is economically and environmentally preferable to good *B*
- $\Psi = 1$ Goods *A* and *B* are economically and environmentally equivalent

The same approach is applied with the ROE and the following equations and decision rules are obtained:

$$ER_{B/A} = \frac{EnvI_A^-}{EnvI_B^-} - 1 = \xi - 1$$

$$ER_{A/A} = 0$$

- $\xi > 1$ Good *B* is environmentally preferable to good *A*
- $\xi < 1$ Good *A* is environmentally preferable to good *B*
- $\xi = 1$ Goods *A* and *B* are environmentally equivalent